P-ISSN: 1693-1246
E-ISSN: 2355-3812
December 2024

Jurnal Pendidikan Fisika Indonesia 20 (2) (2024) 139-147
DOI: 10.15294/jpfi.v20i2.2635

http://journal.unnes.ac.id/journals/jpfi

Simulator for Teaching Computed Tomography Principle

Petr Voda[1]*, David Kordek[1], Daniel Jezbera[2], Pavel Masopust[3], Ales Bezrouk[1]

[1]Department of Medical Biophysics, Faculty of Medicine in Hradec Kralove, Charles University
Simkova 870, 500 03 Hradec Kralove, Czech Republic
vodap@lfhk.cuni.cz
kordekd@lfhk.cuni.cz bezrouka@lfhk.cuni.cz
[2]Department of Physics
University of Hradec Králové,
Rokitanského 62, 500 03 Hradec Králové, Czech Republic
daniel.jezbera@uhk.cz
[3]Mathematics, Physics and Technology
Faculty of Education, University of West Bohemia
Veleslavinova 42, 301 00 Plzen
pmasop@kof.zcu.cz

Received: 15 August 2024. Accepted: 02 November 2024. Published: 31 December 2024

Abstract

Computed tomography (CT) is one of the most important imaging methods in clinical medical practice. Students of medicine have an opportunity to learn about its principles during the classes of the medical biophysics. For a high-quality understanding of the function of CT and to increase the curriculum attractiveness, it is advisable to include such clinical equipment or its simulator in the practical lessons. However, regarding operational safety and related maintenance, CT devices are very expensive and demanding. Therefore, the aim of this work was to create a cheap, operationally easy, and safe CT simulator. The device simulates the principle of CT by transmitting visible light through cubes with a built-in filter of defined attenuation simulating various human tissues. During hands-on training, students first measure radiation intensities without a sample (I_0) and with single cubes (I_i). In the second task, students measure a matrix consisting of four different cubes, irradiating the matrix from different directions and simulating the CT principle. Based on the measurements, the students calculate the linear attenuation of each cube and the corresponding CT numbers and compare the results. The simulator's control is intuitive, provided measurement results are consistent and automatically fed into an interactive report that compares the measured data with the students' calculations, verifies the results, and finally stores them in the database. The main benefit of the study is to bring cheap and effective tools for the demonstration of the CT principle, which can operate each student during the practical lessons, followed by supporting teaching materials.

Keywords: computed tomography, imaging principle, linear attenuation, simulator

INTRODUCTION

Medical biophysics belongs to the cornerstones of education at medical faculties. It is focused mainly on explaining the basic physical principles of physiological processes in the human body and the principles of function of medical devices. However, it is no secret that medical biophysics, as physics in general (Tanti et al., 2021), is not a favorite subject of students of medicine, and that affection often determines their approach to it. Nevertheless, the rapid development of new diagnostic machines based mainly on physical principles gives a very good reason for making this subject more attractive. Future physicians should be aware of the capabilities and limits of available diagnostic machinery.

Computed tomography is one of the important imaging methods used mainly in clinical practice and other applications (Sause, 2016). First-year students of the Faculty of Medicine in Hradec Kralove, Charles University, have an opportunity to learn about the principles of this imaging method during the practical classes in medical biophysics. This paper describes an innovative practical course, Computed Tomography, based on a brand-developed simulator and additional tools such as software and electronic lab reports. The course content is presented by online multiple-step learning courses on three different levels of detail (Bezrouk et al., 2017).

Computed tomography (CT, sometimes incorrectly called computer tomography) is an imaging method that allows the entire body to be imaged in a series of slices using X-rays. The resulting (three-dimensional) image is created by mathematical reconstruction from a series of X-ray projections obtained sequentially from different angles. Computed tomography also images soft tissues and has an essential and still growing role in medical diagnostics (Deniz, 2023). Understanding its principles and those of other imaging methods is very important for the physician, as diagnosis success often depends entirely on the choice of the appropriate imaging method (Jung, 2021). Therefore, teaching the principles of computed tomography is part of the basic course of medical biophysics through lectures and practical exercises.

However, the practical demonstration of computed tomography encounters a number of problems; the actual CT machine is large, expensive, and difficult to operate, and the principle of the imaging method itself can hardly be demonstrated with it. We found several CT simulators Tunissen et al., 2024), all of them are software constructing CT images, or simulate operating real CT machine (Tahmasbi & Behroozi, 2019) but none of them actually demonstrates the physical principle itself. We also have found attempts to construct the technical principle simulator (De Deene, 2019; Liu, F., Lu, Y., & Wang, J., 2006; Vega Mernes, C. A., Francelino, I. G., Kakuno, E. M., & Hönnicke, M. G., 2021), but we do not consider it suitable for demontstrating the principle to students during a practical lesson.

Certain attempts have already been made to innovate the CT teaching curriculum using a simple system containing cubes of various materials, a radioactive radiation source and a scintillation detector to demonstrate the principle of CT. As a part of the modernization of teaching (Kordek, D., Kopecek, M., & Voda, P., 2017), multi-level e-learning teaching materials were developed for this demonstration task (Bezrouk et al., 2017) and these materials and the task itself were integrated into an online system for Distance learning (Masin et al., 2017) and for remote automatic data collection from practical exercise protocols (Hanus, J., Nosek, T., Zahora, J., Bezrouk, A., & Masin, V., 2013; Hanus, J., Zahora, J., Masin, V., & Bezrouk, A., 2013; Zahora et al., 2013).

Although the above-mentioned modifications improved CT teaching, the available demonstration CT device still limited the possibilities of practical exercises, limiting them to semi-frontal teaching.

Therefore, we decided to construct a simple CT simulator that retains the function of demonstrating the principle of computed tomography itself but with a change in the type of radiation and detector. This helped us significantly improve the practical CT exercises and replace the semi-frontal teaching by working in small groups of students so that five groups of four students carry out each task simultaneously. Each of the students thus has the opportunity to work with the CT device during the practical lesson. The use of non-ionizing radiation in the CT simulator also solved the problem of the lack of suitable school radioactive sources and scintillation detectors.

METHOD

Physical principles

Radiation generation in a CT scanner: the basic image information is obtained in principle in the same way as in a conventional X-ray - the patient is illuminated by the X-ray radiation generated in the X-ray tube.

Radiation of the sample: The sample material through which the radiation with initial intensity I0 passes partially prevents the passage of radiation (attenuation, weakening of the intensity), so that the radiation intensity I will be lower behind the sample, which depends on the magnitude of the initial intensity (I0), the material properties (linear absorption coefficient μ) and the thickness of the sample (d) (1):

$$I = I_0 e^{-\mu . d} \tag{1}$$

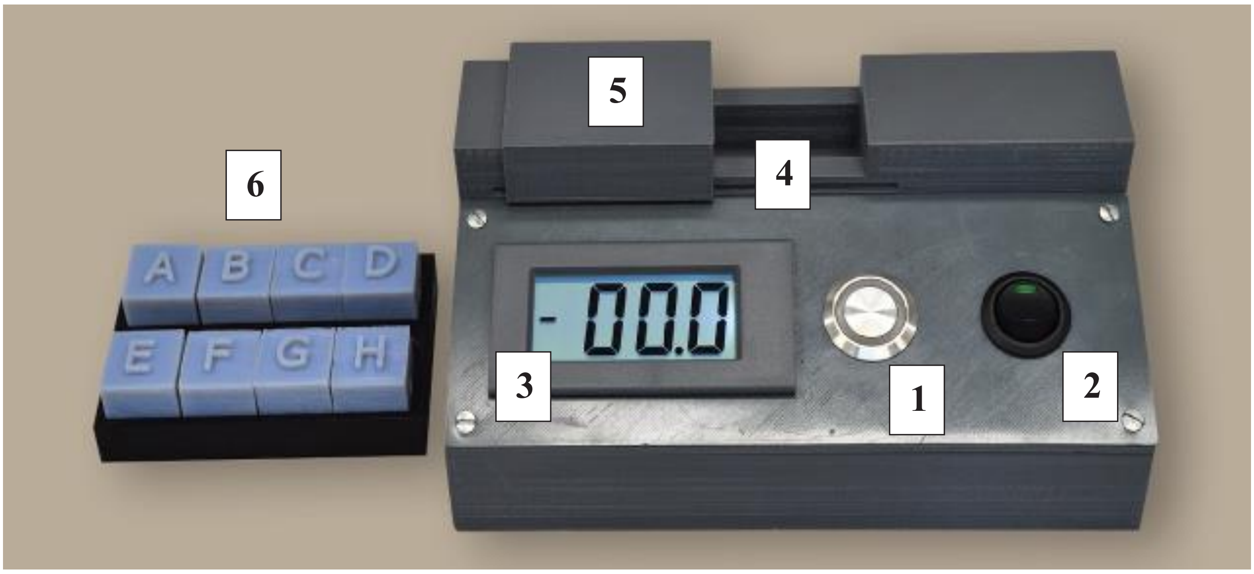

Figure 1. CT principle simulator. 1: measure button, 2: main switch, 3: display, 4: measuring chamber, 5: chamber lid, 6: measured cubes

In practical measurements, therefore, have a known initial radiation intensity I_0 (represented by voltage U_0 measured on the detector with an empty chamber) and a radiation intensity behind the sample I (represented by voltage U measured on the detector with the cube in the chamber) and a known sample thickness (represented by side of the cube) d. We can then determine the linear absorption coefficient μ and use this to determine the material under test:

$$\mu = -\frac{1}{d} ln \frac{I}{I_0} \tag{2}$$

resp.

$$\mu = \frac{1}{d} ln \frac{U_0}{U} \tag{3}$$

These equations (2, resp 3) represent the most important relationship in computing the determination of the linear absorption coefficient from other measured or constant and known parameters, the verification of which is the purpose of the practical exercise and the essence of the simulator presented here.

A CT number scale is widely used to interpret CT scans.

$$CT = 1000 \, \frac{\mu - \mu_{H_2O}}{\mu_{H_2O}} \tag{4}$$

where the CT number (computed tomography number) is expressed in Hounsfield Units (HU), and μ is the attenuation coefficient for the X-ray beam. By definition, vacuum has a value of −1000 HU, and water has a value of 0 HU, thus providing two energy-independent calibration points (Afifi et al., 2020; Bryant, J. A., Drage, N. A., & Richmond, S., 2012).

Simulator Construction

To demonstrate the principle of computed tomography imaging, a simple device is used to measure the attenuation of red light (λ=650 nm) when passing through cubes containing a filter with different light attenuation (μ), made of common plastic films with different transparency, simulating a patient's body containing tissues with different linear attenuation coefficients. The measurement system contains a semiconductor laser LFD650-1-3ADJ-6X17 with a safe power of 1 mW (Picotronic GmbH, Koblenz, Germany) (Picotronic GmbH, 2022) whose light after passing through the dice is incident on the detector, a photodiode BPW21R (Vishay Semiconductors, 2011, 2021). The connected Arduino Nano v 3.0 microcomputer (Arduino, Monza, Italy) (Arduino, 2024), which is now a trendy device to use in such projects Subali, B., Lu'aili, Z., & Sumpono, I., 2019), then displays on a 1x16 I2C display the voltage corresponding to the intensity of the light incident on the detector. The simulator is powered via a USB port from a universal 5V power supply or from a connected PC. The measured results can be directly transferred to a PC program created in the Processing environment.

The body of the simulator consists of three parts. The bottom part houses the electronics and the USB connector. The upper part contains the test chamber, laser, detector, display, switch and button. The third part is a sliding cover for the test chamber that prevents visible light from entering. The next part of the assembly are the cubes (8 in total, the student will use 4 of them randomly in the task) with holes on the sides for light to enter and exit and a cavity into which the attenuation film is inserted. Each cube has an identifying letter on the top. All the parts were designed at the Institute of Medical Biophysics in the 3D printing laboratory and printed on a 3D printer with a common PLA material (Figure 1).

Analysis of CT simulator functionality

To test the functionality and reproducibility of the results provided by the CT simulator, 294 medical students performed the CT measurements in the winter semester of the academic year 2023 - 2024. Each student received a random combination of 4 cubes out of 8 cubes marked A-H. Four cubes with the highest frequency of use were selected. Cube A was used 228 times, B in 220 times, C in 220 times, and D in 224 times. The measurement data were analyzed using MS Excel 2016 (Microsoft Corp., Redmond, WA, USA) and statistical SW NCSS 10 (2015, NCSS, LLC., Kaysville, UT, USA, Available at: ncss.com/software/ncss [accessed on 21 April 2023]). Since the data were not from a population with a normal distribution, the median the 1st quartile, and 3rd quartile $\tilde{x}$ (1stQ; 3rdQ) were used for their description.

Figure 2. task 1 principle

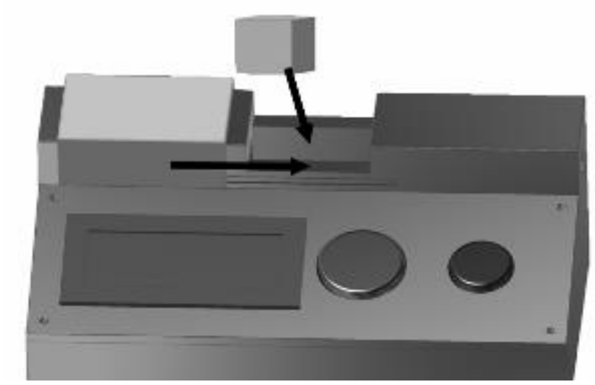

Figure 3. CT simulator in task 1 – inserting the cube

RESULT AND DISCUSSION

Simulator in practical exercises:
Measurement task 1:

The aim of the task is to verify the relationship to determine the linear absorption coefficient of a material. The student's task is to find the linear absorption coefficient and the CT number by measuring one cube (Figure 2). First, the intensity I_0 (represented by voltage U0) is measured with an empty closed chamber. The cube with the absorbing foil is then placed in the center of the measuring chamber (Figure 3) and the I_1 value (resp. voltage U1) appears on the display when the button is pressed. This is repeated 3 times for each sample. And the same operation is maintained for the other 3 cubes.

The student fills in the observed values in the electronic log and calculates the average intensities using equation (3) for each sample and, from these, calculates the CT numbers using equation (4). If a PC program is used, the transfer of values from the simulator is done automatically when a button is pressed in the program.

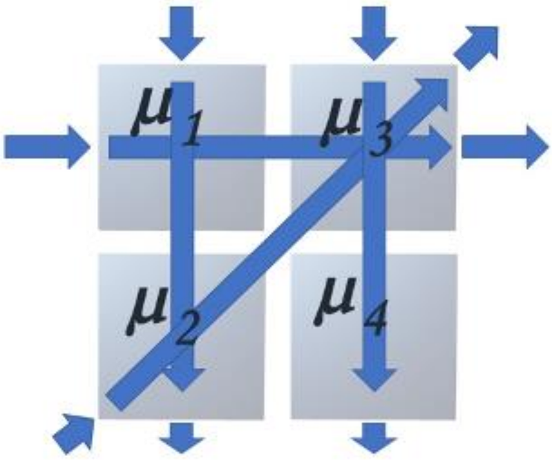

Figure 4. Task 2: the group of four cubes radiated from various directions

Measurement task 2:

Verification of the principle of the CT machine. Measurement of the linear attenuation coefficient of a system of materials and determination of individual materials by projection from different angles. The student's task is to determine the linear absorption coefficients and CT numbers of four different materials represented by cubes with different filters by measuring a quartet of cubes simulating a group of tissues with different properties. Measurements of pairs of cubes, representing measurements of a group of materials from different directions, are used. The result of the measurement is a radiation intensity (represented by the voltage measured on the detector) proportional to the cumulative attenuation by the pair of cubes. From this intensity, the student calculates the cumulative linear coefficient for the dice pair according to (3). The student then constructs a system of linear equations with multiple unknowns, which is used to calculate the linear attenuation coefficients of the individual dice and then their CTs. This demonstrates the second main principle of computed tomography, which gives the method its name.

The student randomly chooses four cubes and assembles them into a 2x2 matrix, which is then scanned from different directions (Figure 4). This is done by successively inserting the corresponding irradiated pair of cubes into the measuring chamber, resulting in the radiation intensities for each pair (example in Figure 5).

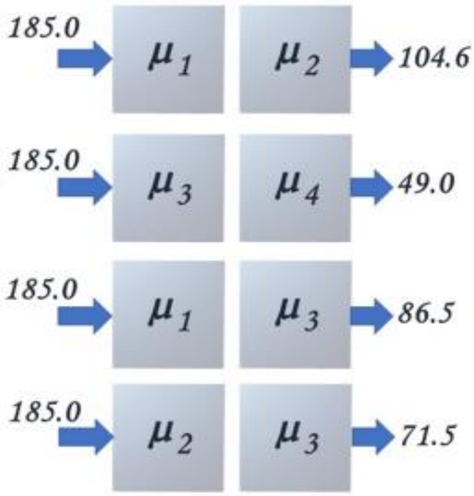

Figure 5. Task 2: measured voltages in mV representing intensities for various pairs of cubes

By calculating (3), the student obtains the cumulative attenuation coefficients for the dice pairs (example in Figure 5). From these, the linear absorption coefficients of the individual cubes can then be calculated using a system of equations (example in Figure 6), and the individual CT numbers can then be calculated using (4).

- $\mu_1 + \mu_2 = y_1 = 0.285$
- $\mu_3 + \mu_4 = y_2 = 0.665$
- $\mu_1 + \mu_3 = y_3 = 0.380 \rightarrow \mu_3 = y_3 - \mu_1 = 0.380 - \mu_1$
- $\mu_2 + \mu_3 = y_4 = 0.475 \rightarrow \mu_2 = y_4 - \mu_3 = 0.475 - \mu_3$

Figure 6. Task 2: a system of equations for calculating linear absorption coefficients for each cube

The measurements are again performed 3 times for each pair of cubes. The student fills in the detected values in the electronic report and calculates the average intensities for each pair and then the cumulative absorption coefficients for the pairs of cubes. The system of equations is then used to determine each cube's individual linear absorption coefficients and CT numbers. In case a PC program is used, the transfer of the values from the simulator is done automatically by pressing a button in the program.

Software tools, electronic learning materials

As already mentioned in the introduction, software tools are part of the measurement tasks. The simulator can be connected via a USB port to a PC with the program "CT Simulator", which provides an automatic transfer of the measured values from the simulator to the PC (Figure 7).

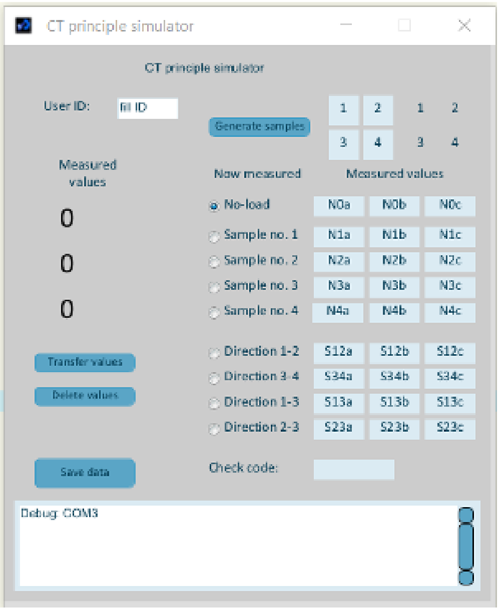

Figure 7. The program provides an automatic transfer of the measured values from the simulator to the PC

The measured values can be saved or sent to an electronic log. The electronic interactive log (Laboratory report) is an MS Excel (Microsoft Corp., Redmond, WA, USA) sheet with predefined graphics and functions, which is used to record and automatically check the measured and calculated values (Figure 8, 9). The student manually or with the help of a transfer program fills in the corresponding cells colored in grey with the measured values. He/she then calculates the other values (intensity averages, absorption coefficients and CT numbers) from these measured values and fills in the cells colored in red.

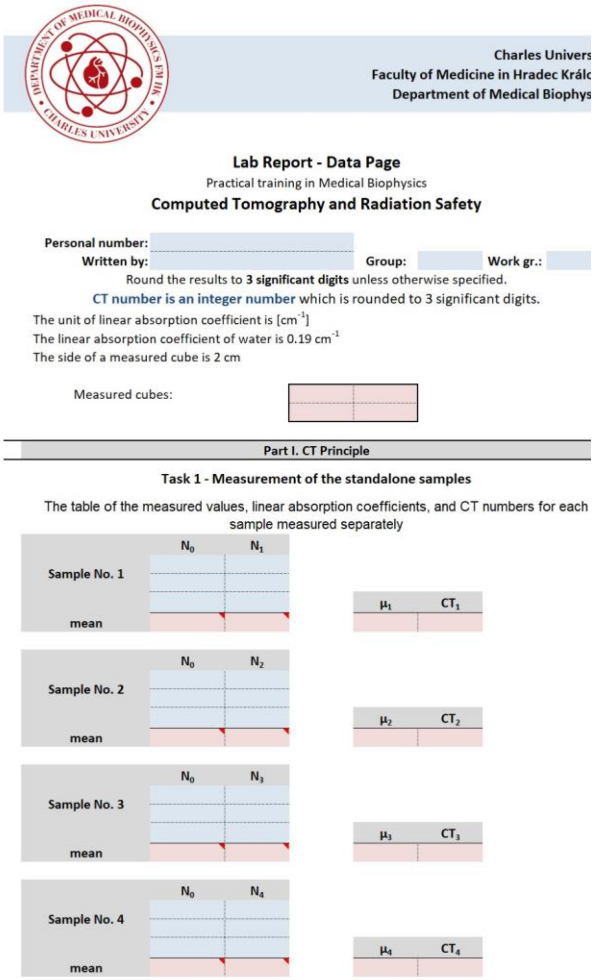

Figure 8. The interactive laboratory log in MS Excel

The background of the log contains locked control functions, a set of formulas, and functions programmed to review the student's calculations. If the calculations (with a predetermined range for rounding) are correct, the initially red cell fills turn green.

When all these checks are successful, the "submit" button becomes active, and the log can be submitted to the central log database. The simple numerical values are also sent (also using the functions programmed under the button) to the university ambulatory system. The laboratory task also includes interactive teaching materials in the form of multi-stage e-learning for student preparation, which are part of a complex of materials for interactive teaching of medical biophysics in LMS Moodle (Kurniawan, B. R., Rahmawati, I., & Fawaiz, S., 2023), and a didactic video tutorial guiding students in detail with the simulator. All these teaching materials have their own mobile version, which students use on their mobile devices directly during the lesson, which also increases its effectiveness and attractiveness. (Kutluk & Gülmez, 2014; Taleb, Z., Ahmadi, A., & Musavi, M., 2015)

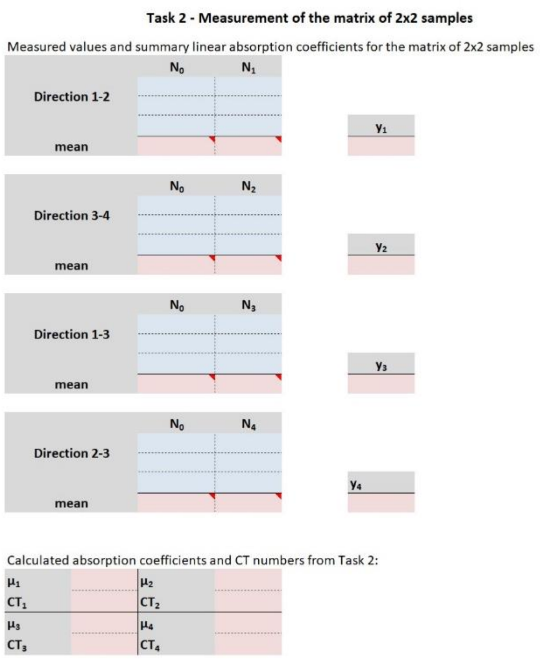

Figure 9 The interactive laboratory log in MS Excel

The measurement results recalculated and expressed as CT numbers of the four selected cubes show acceptable measurement reproducibility (Figure 10). The maxima in the histograms of CT numbers of individual cubes correspond to the medians found when for cube A, the median CT is 847 (-807; 305), cube B is 780 (-760; 756), cube C -592 (-359; 753), and cube D 1070 (1740;2460). Noticeable additional frequency peaks at high-value CT numbers in the histograms of cubes B, C, and D (Figure 10) are most probably caused by the incorrect orientation of the cube in the simulator, fully blocking the probing light. On the other hand, the frequency peak at low-value CT numbers (Figure 10) in the histogram of cube D and the possible increase in the low-value CT frequency peaks in the histograms of cubes A, B, and C are probably caused by incorrect probe beam calibration or performing the measurement without the box in the measuring chamber.

Nevertheless, the CT simulator device's reproducibility for teaching and demonstration purposes could be considered completely satisfactory.

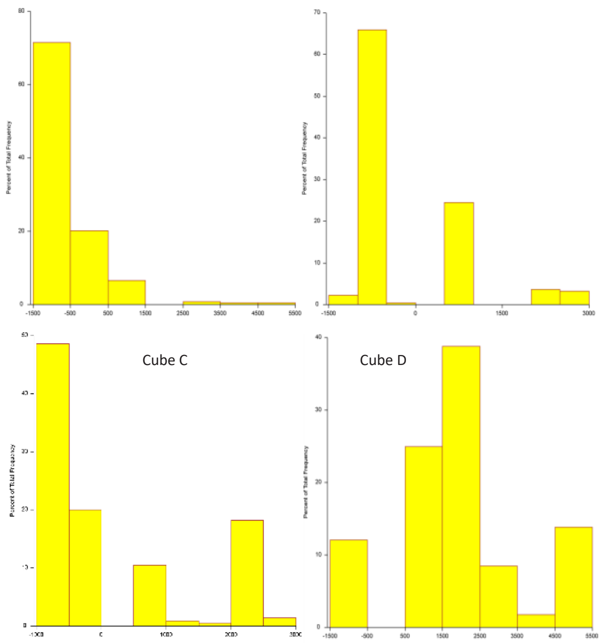

Figure 10. Histograms of CT numbers of individual cubes.

CONCLUSION

The new CT simulator proved to be fully suitable for teaching the practical classes of computed tomography. The simulator's control is intuitive, provided measurement results are consistent and automatically fed into an interactive report. The report automatically compares the measured data with the students' calculations, verifies the results of the calculations, and finally stores the results in the report database and the ambulatory system. Using multiple devices during the practical classes enabled all students to experience the principles of computed tomography function, increasing the subject's attractiveness. The innovative structure of the practical exercises proved to be better than the old version, with the experiment performed on a single device. The linking to learning materials, data transfer to PC, and automatic evaluation significantly saves the time needed to successfully complete the practical measurement class, giving students the opportunity to learn in more detail the principles of CT as each student independently solves their own measured data on their samples. Composed not only of measurements but also of supporting teaching materials, the course also helps students to better understand the key physics principles of the topic, thanks to multi-level e-learning interactively adapted to each student's actual needs.

REFERENCES

Afifi, M. B., Abdelrazek, A., Deiab, N. A., Abd El-Hafez, A. I., & El-Farrash, A. H. (2020). The effects of CT x-ray tube voltage and current variations on the relative electron density (RED) and CT number conversion curves. *Journal of Radiation Research and Applied Sciences*, *13*(1), 1–11. https://doi.org/10.1080/16878507.2019.1693176

Arduino. (2024, April 4). *Nano | Arduino Documentation*. https://docs.arduino.cc/hardware/nano/

Bezrouk, A., Nosek, T., Smutny, M., Kopecek, M., Voda, P., Hanus, J., & Stransky, P. (2017). (msl) Multiple Step E-Learning Practical—Computed Tomography. In M. Hruby (Ed.), *Distance Learning, Simulation and Communication "Dlsc 2017"* (pp. 9–14). Univ Defence, Brno. https://www.webofscience.com/wos/woscc/full-record/WOS:000451519900001

Bryant, J. A., Drage, N. A., & Richmond, S. (2012). CT number definition. *Radiation Physics and Chemistry*, *81*(4), 358–361. https://doi.org/10.1016/j.radphyschem.2011.12.026

De Deene, Y. (2019). Teaching the principles of X-ray CT and SPECT using optical CT, glowsticks and a scaled anthropomorphic phantom. *Journal of Physics: Conference Series*, *1305*(1), 012058. https://doi.org/10.1088/1742-6596/1305/1/012058

Deniz, C. (2023). Modern Computer Tomography with Artificial Intelligence and Deep Learning Applications. *Artificial Intelligence Theory and Applications*, *3*(2), Article 2.

Hanus, J., Nosek, T., Zahora, J., Bezrouk, A., & Masin, V. (2013). On-line integration of computer controlled diagnostic devices and medical information systems in undergraduate medical physics education for physicians. *Physica Medica - European Journal of Medical Physics*, *29*(1), 83–90. https://doi.org/10.1016/j.ejmp.2011.12.002

Hanus, J., Zahora, J., Masin, V., & Bezrouk, A. (2013). On-line Incorporation Of Study And Medical Information System In Undergrduate Medical Education. In L. Chova, A. Martinez, & I. Torres (Eds.), *6th International conference of education, research and inovation (ICERI 2013)* (pp. 1500–1507).

He, L., Lu, W., Wang, Z., Wang, S., & Xue, M. (2022). CTSim: A numerical simulator of computed tomography for high-quality radiological education. *International Journal of Computer Assisted Radiology and Surgery*, *17*(7), 1257–1269. https://doi.org/10.1007/s11548-022-02656-6

Joemai, R. M. S., Geleijns, J., & Veldkamp, W. J. H. (2010). Development and validation of a low dose simulator for computed tomography. *European Radiology*, *20*(4), 958–966. https://doi.org/10.1007/s00330-009-1617-x

Jung, H. (2021). Basic Physical Principles and Clinical Applications of Computed Tomography. *Progress in Medical Physics*, *32*(1), 1–17. https://doi.org/10.14316/pmp.2021.32.1.1

Kordek, D., Kopecek, M., & Voda, P. (2017). Medical biophysics as a combination of the traditional educational method and e-learning. In M. Ganzha, L. Maciaszek, & M. Paprzycki (Eds.), *Proceedings of the 2017 Federated Conference on Computer Science and Information Systems (fedcsis)* (pp. 177–180). Ieee. https://doi.org/10.15439/2017F369

Kurniawan, B. R., Rahmawati, I., & Fawaiz, S. (2023). E-Module Implementation by Using Feature-Lesson-Based of Moodle in Physics Learning Multimedia Practices for Students of Prospective Physics Teacher. *Jurnal Pendidikan Fisika Indonesia*, *19*(1), 76–88. https://doi.org/10.15294/jpfi.v19i1.37176

Kutluk, F. A., & Gülmez, M. (2014). A Research about Mobile Learning Perspectives of University Students who have Accounting Lessons. *Procedia - Social and Behavioral Sciences*, *116*, 291–297. https://doi.org/10.1016/j.sbspro.2014.01.210

Liu, F., Lu, Y., & Wang, J. (2006). *Development of computed tomography instrument for college teaching*. *29*, 556–560.

Masin, V., Rezacova, M., Vavrova, J., Paluska, P., Kopecek, M., Voda, P., Hanus, J., & Stransky, P. (2017). A Cooperative Approach to Distance Learning in Radiobiology. In M. Hruby (Ed.), *Distance Learning, Simulation and Communication "Dlsc 2017"* (pp. 106–112). Univ Defence, Brno. https://www.webofscience.com/wos/woscc/full-record/WOS:000451519900015

Picotronic GmbH. (2022). *LFD650-1-3 datasheet*. https://www.picotronic.de/picopage/en/product/detail/id/359583

Rahmatullah, R., & Suparno, S. (2020). The Development of Experimental Absorption Based on Arduino-Uno and Labview on Light Radiation by Colourful Surface. *Jurnal Pendidikan Fisika Indonesia*, *16*(1), 41–46. https://doi.org/10.15294/jpfi.v16i1.23596

Sause, M. G. R. (2016). Computed Tomography. In M. G. R. Sause, *In Situ Monitoring of Fiber-Reinforced Composites* (Vol. 242, pp. 457–532). Springer International Publishing. https://doi.org/10.1007/978-3-319-30954-5_6

Subali, B., Lu'aili, Z., & Sumpono, I. (2019). Development of Ultrasonic Sensors Based Mechanical Energy Experiments. *Jurnal Pendidikan Fisika Indonesia*, *15*(1), 29–38. https://doi.org/10.15294/jpfi.v15i1.19308

Tahmasbi, M., & Behroozi, H. (2019). *Comparing learning level and students' attitudes toward radiology training through the use of computed tomography simulators and traditionally training devices at Ahwaz University of Medical Sciences*.

Taleb, Z., Ahmadi, A., & Musavi, M. (2015). The Effect of M-learning on Mathematics Learning. *Procedia - Social and Behavioral Sciences*, *171*, 83–89. https://doi.org/10.1016/j.sbspro.2015.01.092

Tanti, T., Astalini, A., Kurniawan, D. A., Darmaji, D., Puspitasari, T. O., & Wardhana, I. (2021). Attitude for Physics: The Condition of High School Students. *Jurnal Pendidikan Fisika Indonesia*, *17*(2), 126–132. https://doi.org/10.15294/jpfi.v17i2.18919

Towbin, A. J., Paterson, B. E., & Chang, P. J. (2008). Computer-based Simulator for Radiology: An Educational Tool. *RadioGraphics*, *28*(1), 309–316. https://doi.org/10.1148/rg.281075051

Tunissen, S. A. M., Oostveen, L. J., Moriakov, N., Teuwen, J., Michielsen, K., Smit, E. J., & Sechopoulos, I. (2024). Development, validation, and simplification of a scanner-specific CT simulator. *Medical Physics*, *51*(3), 2081–2095. https://doi.org/10.1002/mp.16679

Vega Mernes, C. A., Francelino, I. G., Kakuno, E. M., & Hönnicke, M. G. (2021). A simple and low cost USB webcam-driven optical tomography system suitable for teaching x-ray computed tomography. *European Journal of Physics*, *42*(4), 045301. https://doi.org/10.1088/1361-6404/abf021

Vishay Semiconductors. (2011). *BPW21R datasheet, Doc. No. 81519*. Vishay Semiconductors. https://www.vishay.com/docs/81519/bpw21r.pdf

Vishay Semiconductors. (2021). *Application note—Ambient Light Sensors*. Vishay Intertechnology, Inc. https://www.vishay.com/docs/84154/appnotesensors.pdf

Zahora, J., Hanus, J., Jezbera, D., & Bezouk, A. (2013). Remotely controlled laboratory and virtual experiments in teaching medical biophysics. In L. Chova, A. Martinez, & I. Torres (Eds.), *6th International conference of education, research and inovation (ICERI 2013)* (pp. 900–906).